APPENDIX F
Earth Sciences and Applications

INTRODUCTION

Space accomplishments over the past 10 years have tremendously advanced our understanding of the Earth and our capabilities for long-distance communication and navigation. Projected programs over the next several years are designed to capitalize on this early investment and produce even more remarkable gains. Examination of the needs in the various disciplines of the Earth Sciences and Applications program, however, indicates that the requirements for observations and operations in Earth orbit far exceed these plans. The period 1975-1985 could be one of the most informative and beneficial eras of our space age for the people of this Earth if these needs are pursued in an aggressive manner.

OBJECTIVES

The objectives for an Earth Sciences and Applications program might be conveniently stated as follows (ref. 1):

1. A more precise knowledge and understanding of man's environment on Earth and of the forces controlling it, to allow accurate short and long term forecasting and to allow man's eventual control of his environment.
2. A more precise knowledge, inventory, and use of the Earth's resources, particularly those of the United States.
3. The extension of communications of all types to world-wide coverage, particularly to the areas inaccessible by past techniques, to greatly improve the efficiency, economy, and reliability of communications, worldwide and national.
4. The development and adoption of systems of navigation and traffic control to achieve safe, economical, and swift air and sea transportation at much higher traffic densities.
5. The accurate location of geographic features.

SPACE ACCOMPLISHMENTS AS OF 1968

NASA's flight program of space experiments is preceded by a ground-based research phase. Early experiments in space either determine the need for further basic research, or they can progress to the development of an operational flight system. In three of the five areas mentioned in the section "Objectives" (p. 85), NASA has already achieved first-generation operational systems. These include meteorology, which is part of objective (1), communications (3), and geodesy (5). The other two areas have not yet advanced beyond the early stages of flight investigation.

TERRESTRIAL ENVIRONMENT (EXCLUDING RESOURCES)

Most of the activity in this area has been in meteorology. The early Tiros satellite has achieved operational status (operated by the Environmental Science Services Administration) and currently provides imagery of the Earth's cloud cover during daylight hours. Operating in Sun-synchronous orbits, two types of cameras are carried on different spacecraft. The automatic picture-transmission (APT) camera provides direct readout to ground stations with inexpensive receivers, while the advanced vidicon camera system (AVCS) stores its data on magnetic tape and requires special ground receiving equipment. Ground resolution is about 1 kilometer from 800-kilometer altitude for the AVCS camera.

The Nimbus satellite program provides a test bed for new sensor instruments, as well as providing meteorological data for operational use. The high-resolution, infrared, radiometer scanning system senses thermal radiation from land, water, and cloud surfaces and produces imagery of the nighttime hemisphere in the 3.6- to 4.2-micron region of the spectrum (ref. 2). Ground resolution is about 8 kilometers, and the accuracy of the temperature measurements is about 1° K. Five-component multispectral imagery (ground resolution of ~50 kilometers from 1100-kilometers altitude) between the visible and 30-micron region has

revealed information on the temperature and water-vapor content of different regions of the atmosphere. This type of experiment was also carried on Tiros III, IV, and VII.

Operating at geosynchronous altitudes, the Applications Technology Satellite (ATS) program has provided synoptic (black and white, and color) photography of time-varying cloud systems, including a number of storm phenomena (ground resolution of ~4 kilometers with the spin-scan camera).

In addition to meteorology, the Terrestrial Environment discussion in this paper includes the disciplines of geology, oceanography, and hydrology. Gemini photos have been used for the study of large-scale geologic features which far exceed the range of coverage of aerial photography surveys (ref. 3). Satellite optical imagery has also provided data on such things as pack-ice distribution on the ocean, snow cover on the land, and the location of water in remote areas. Nimbus high-resolution, infrared-radiometer (HRIR) imagery has detected ocean currents through their surface temperature differences.

EARTH RESOURCES

As part of a preliminary research program, a number of Earth resources-oriented sensors have been flown on aircraft to determine appropriate techniques for data gathering and interpretation. These are aimed at such resources as minerals, water, and agriculture. Space-flight data of potential interest to the mining and fishing industry, for example, have been provided by the Gemini, Tiros, and Nimbus programs, although these were not the prime experiments. Specific resource-oriented satellites have not yet been flown.

COMMUNICATIONS

The NASA communications satellite program, which began with the Echo balloon in the early 1960's, has progressed through the Relay system, capable of one-way television or 300-channel telephony, to the present operational Intelsat program, capable of transmitting television or up to 240 voice channels from point to point (from geostationary orbit). In addition, the ATS program is carrying out communications experiments for possible future space-operational systems (ref. 4). Examples of these experiments include: (1) a microwave communications transponder capable of

operating in either a wideband or narrowband access mode; (2) an electronically despun microwave antenna; and (3) a VHF transponder with associated electronically despun antenna.

NAVIGATION, TRAFFIC CONTROL, AND DATA COLLECTION

NASA is just beginning experiments in this area of the ATS program to determine the locations of surface and airborne craft. ATS-C (1967) carried an experiment involving a transponder to use the Navy's Omega Navigational System for craft position determination.

GEODESY

One major objective of the National Geodetic Satellite program is the establishment of a network of about 90 control stations around the world with a positional accuracy of ±10 meters. The successful launch of Geos II in January, 1968, may provide enough data to complete this objective, although an additional Geos could be required.

The second major objective of this program—a description of the Earth's gravity field out to the 15th harmonic—is being met largely by tracking various satellites already in orbit.

THE NEEDS IN EARTH SCIENCES AND APPLICATIONS AS WE SEE THEM TODAY

TERRESTRIAL ENVIRONMENT

Meteorology

Weather Forecasting

At the present stage, weather forecasting is primarily based on ground-based observations (refs. 5 and 6), with the data from meteorological satellites playing a secondary role in filling in some gaps in these data (such as providing storm warnings). Operational use of global-circulation models, extending the forecasting period to

1 to 2 weeks, will require a continuous supply of global data on atmospheric variables. Such a network is likely to encompass thousands of long-lived balloons in the stratosphere, a number of satellites in a variety of orbits, and a battery of ground stations.

The estimated minimum continuous-data requirements for effective weather prediction include: (1) atmospheric-mass field (given by temperature and pressure) and wind vectors (in the tropics), (2) the coarse distribution of tropospheric humidity, and (3) the distribution of clouds. These parameters must be measured as a function of latitude, longitude, and height. Observations must be obtained over the entire globe, and made at regular intervals once or twice in each 24-hour period. Initially, a horizontal grid spacing of about 500 kilometers between observations at several (three to nine) altitude levels below about 35 kilometers is needed.

Heat Budget

One of the key problems in meteorology, which focuses the needs for observational data and increased understanding, is the question of the heat budget of the Earth's surface and atmosphere. This budget depends on a very delicate balance of the radiation incident from the Sun, its reflection, scattering, and transmission by the atmosphere, the radiation absorbed by the Earth's surface and re-emitted, and the passage of this re-emitted radiation through the atmosphere (ref. 7). Key factors in adjusting the heat budget are the water vapor, carbon dioxide, and ozone concentrations in the atmosphere, its cloudiness, and turbidity caused by aerosols. It is not entirely clear how much of the greenhouse effect is to be attributed to carbon dioxide and how much to water vapor, nor are sufficient quantitative data available on cloudiness. Even less is known of atmospheric turbidity. This permits only crude estimates on secular variations of the terrestrial heat budget. The most sophisticated computations (refs. 8 to 10) show that an increase or decrease by a factor of 2 in CO_2 concentration is accompanied by a surface temperature change of 2 to 3° C; no account was taken in this computation of atmospheric turbidity.

Scattered observations over the last century indicate that the CO_2 content of air in the northern hemisphere has increased from ~280 ppm in 1860 to ~320 ppm in 1960; this is most likely because of the burning of fossil fuels. Observations carried out on a

regular basis since IGY show a steady rate of increase of 0.7 ppm/year over the last decade. But data over most regions of the world are still lacking. A steady heating trend of the surface temperature was evident until the 1940's, which was ascribed to the increase of CO_2 concentration. Since then, this trend appears to have been reversed; this is tentatively attributed to the increase in turbidity. The latter appears to have been mounting at a rate of tens of percent per year (ref. 11).

Relatively coarse but selective measurements (as described above) directed at simple atmospheric parameters may be sufficient even for long-range (~2 weeks) weather forecasting. A truly quantitative understanding of the Earth's heat budget, however, and a realistic assessment of trends occurring in it require increasingly refined measurements on a global scale of both the distribution of components critical for the terrestrial heat balance, and of the different components of solar and terrestrial radiation. To separate these, spectral and spatial resolutions may be required that far exceed those needed for the conventional meteorological purposes of the future.

Weather and Climate Modifications

A 1966 report by the National Academy of Sciences (ref. 12) reviewed the current progress and problems in weather modification. Some of the conclusions are summarized as follows. On the subject of fogs and clouds: (1) data on the effects of cloud seeding for precipitation control are largely ambiguous; and (2) dissipation of localized "cold" fogs is practicable, but there has been little recent progress with respect to "warm" fogs. On the subject of large-area weather and climate modification: At our present stage of understanding, "to embark on any vast experiment in the atmosphere would amount to gross irresponsibility."

Unfortunately, man is inadvertently modifying the atmosphere (and its surface interface) by increasing the CO_2 content, polluting the air and water with heat and chemicals, and changing the radiative properties of the surface by the construction of cities.

Clearly we wish to know the short- and long-term effects of inadvertent climate modification. There are also positive changes in our weather which would be desirable to implement. The above report (ref. 12) outlines a series of recommendations for both field investigations and studies, all of which require data that are not

presently being obtained. Much of this is required on a continental or global basis and is best obtained by satellites.

Geology (Excluding Resources)

Many geologic occurrences, such as mountain building, faulting, and sea-floor spreading take place on a continental or global scale. Some of the resulting features would be evident in surface imagery. However, the view of the geologist has been limited, with aircraft regional surveys providing the greatest perspective (single pictures cover less than 10 miles on a side). The need here is for photography of large areas for the purpose of investigating basic geological problems involving features extending over hundreds to thousands of miles, and which may be located in such remote areas as central Asia, the African rift valleys, the Amazon basin, and the Arabian desert. To photograph such areas by conventional aerial and surface methods would be extremely expensive and time consuming, in addition to presenting problems of cartographic control.

While most of the geology referred to above is more or less constant over the lifetime of any proposed observation program, there are short-term occurrences for which comparative "before and after" pictures are the most revealing measure of what has happened. For example, coastal geology of a continent can change markedly over a period of years, if erosion conditions are severe enough. Visible changes in the Earth's crust caused by earthquakes may also be detected in this way.

In the case of other transient phenomena where the active process may actually be observed, volcanic eruptions and other dynamic thermal activity are candidates of interest. The need here is to monitor for the occurrence of such events, with the possibility of predicting and locating potential catastrophes. In the case of volcanoes, the perspective of orbital observation would also be an advantage in estimating the amount of ash thrown into the atmosphere. Volcanoes are important to the atmospheric heat budget problem, as they are a source of atmospheric turbidity which counteracts the effect of increased CO_2 by decreasing the amount of visible sunlight reaching the lower atmosphere and surface.

Earthquake prediction and damage assessment are another significant area of geology. A number of surface in situ measurements have been suggested, with the possibility that a significant change in any one of several parameters might provide a few hours or days notice of impending disaster (ref. 13). The satellite application here would be the collection of transmitted data from implanted ground sensors.

Oceanography (Excluding Resources)

In a 1966 report, the National Academy of Sciences (ref. 14) summarized the areas in oceanographic research where, although some new insights had been achieved, much remained to be done. In physical oceanography alone (as opposed to marine chemistry and biology, for example), eight areas were cited where sufficient understanding and availability of data are lacking. These include:

Near-surface currents and their seasonal variations.—Both direct and indirect measurements are being made of near-surface current properties, but the view is far from synoptic.

Deep circulation and oceanic structure.—New measurements of deep-ocean properties are causing old theories to be revised or rejected.

Scales of motion in the sea.—The energy content in sea motions at frequencies below one cycle per day tends to increase with decreasing frequency. There is a requirement for long-term observations over large areas.

Upwelling and upward mixing.—Cold water rising to the surface can have a profound effect on local weather and climate.

Turbulence and diffusion.—There is a large amount of turbulence caused by wind and waves in the near-surface layer, but the energy budget and the way in which the energy is dissipated are not known in detail.

Internal waves.—Internal waves at tidal frequencies have been detected, but in general, their origin and frequency of occurrence are unknown.

Surface waves.—Wind-driven, sea-surface waves can be predicted if the wind field is known—which it generally is not.

Ocean tides.—World-wide measurements of tidal variations have both oceanographic and geophysical implications.

Any coordinated program of research and data collection designed to investigate these several areas should include ships,

buoys, and satellites. Certainly for the vast bulk of the oceans beneath the immediate surface, satellite observations are of limited value. However, satellites will still play an important role as part of the data-collection system.

In a recent draft report by the National Council on Marine Resources and Engineering Development–Committee on Ocean Exploration and Environmental Services (April 25, 1968), a 10-year plan for ocean exploration and mapping (TYPOE) is outlined. This is an interagency plan for the 1970's, designed to coordinate the efforts of the Departments of Commerce, Defense, Interior, and Transportation, in addition to agencies such as NASA, the AEC, and the NSF. Interestingly enough, the implementation plan that concludes the report is based solely on the use of ships–approximately a hundred of them. Ships have clear advantages in direct surface measurements and subsurface soundings, but they have equally clear disadvantages in extent of coverage. Many of the needs for observational data that are outlined for both the U.S. continental margins and the deep oceans may best be satisfied, at least in part, by satellite observations. Among these are included:

1. Monitoring nutrients, dissolved gases, and chemical and radionuclide pollutants in the shelf areas of the U.S.
2. Data in support of studies of the Labrador Current, especially as it transports icebergs and affects Gulf Stream dynamics.
3. Further data in support of existing studies of North Pacific Ocean currents, especially the Kuroshio-Oyashio Systems and the California Current, if the large-scale dynamics are to be understood.
4. Data on the effect of the extent of sea-ice cover in the Arctic Ocean on global circulation patterns and the climate of North America.

It should be clear that the problems in oceanography cannot be completely separated from those of other disciplines. Considering the question of the atmospheric heat budget, for example, the CO_2 content of the oceans is roughly 50 times that of the atmosphere. Changes in the content of either one can upset the thermodynamic equilibrium. Pack ice floating in the polar regions reflects about three-fourths of the incident solar illumination and modifies the energy exchange between the ocean surface and atmosphere. The temperature and sea state of the oceans' surface water are also important contributors to this exchange.

Hydrology (Excluding Resources)

Much of the interest in hydrology is in its use as a resource study; this subject will be considered in the following section. However, nonresource needs for hydrologic data can arise, for example, in connection with the heat-budget problem. A typical instance is a situation in which lower temperatures accompanied by increased precipitation result in glaciation. Various authorities have estimated that if the average temperature should decrease by 1.5° to 8° C, glaciers would again cover an appreciable fraction of the Earth's surface (ref. 10). One of the central questions motivating the recent years of Antarctic investigation has been: Is the amount of ice remaining constant, or is there gradual melting? If a small percentage of this ice were to melt, the world's coastal cities would be flooded. Based on results to date, Dr. Albert Crary, Antarctic specialist for the National Science Foundation, has commented: "One area or another may be out of balance—precipitation and ice flow vary—but on the average, the amount of ice seems to be remaining about the same" (ref. 15).

Another important contributor to the heat-budget problem is plantlife, which depends for its sustenance upon the availability of water. Plants are the major organic users of atmospheric CO_2, taking it out of the atmosphere during photosynthesis. The organic cycle replaces this CO_2 through the processes of respiration and decay, and equilibrium is approximately maintained. The annual exchange volume in this organic cycle far exceeds that caused by man's burning of fossil fuels or the volume included in the inorganic exchange cycle. The extent of plant growth depends on climatic factors, such as temperature and precipitation, as well as inorganic soil components.

EARTH RESOURCES

Our natural resources are limited in quantity. In order to insure that the appropriate planning is done whenever there is a dependence on these resources, it is necessary to have an up-to-date inventory of the status of each resource. In general, these resources are distributed throughout the world, so that a global survey technique is required. While some resources are relatively stable with time, others, such as in agriculture, can change markedly in a period of several days. The availability of current inventories is an

economic advantage to the United States, and it could also become a vital information factor in our international relations.

Examples of Earth resources that may be subject to satellite survey are:

Oceanography.—Coastal water pollution, fish school migration, sea state (for shipping), and sea-ice location (also for shipping).

Hydrology.—Water storage in snow and ice cover and in lakes and reservoirs; water pollution.

Agriculture.—Detection of crop disease and prediction of crop yield.

Geology.—Mineral sensing and inventory.

A number of attempts have been made to estimate worldwide "dollar benefits" that might accrue from a vigorous program of space observations. Table F-I (refs. 16 and 17) shows estimates of annual benefits made by three relatively independent groups. The point to be made is that "benefits" could be measured in terms of billions of dollars. However, most individual proposals have not been tested. The Space Applications Summer Study group (ref. 6) emphasized that the time had come for substantial investments of venture capital; that the current NASA budget in this area ($100 million) was too small by two to three times, at least. They deemphasized benefit estimates for any one application, urging that the overall return would be large, certainly much greater than the cost of achieving this return.

COMMUNICATIONS

With the formation of Comsat and the partial completion of its satellite network, our immediate goals in point-to-point communications are nearing realization. Looking to the future, the needs for space communications may be divided into four areas.

Improved frequency utilization.—One of the key areas here is the investigation of the usefulness of the frequency spectrum below 1 GHz and above 10 GHz. Millimeter waves are particularly important, as they would provide increased antenna gain per unit area and possibly increased bandwidth.

Small user/multiple access communication.—Eventually the need will arise to provide voice and data links between small-capacity users and remote ground terminals on a reliable, low-cost basis. The small users may be aircraft, ships at sea, or small mobile or fixed ground stations. This would require constant satellite coverage with

Table F-I.—*Dollar Benefits from Space Applications (Worldwide) ($ 10^6 where quantified)*

Activity	TRW[a] (ref. 16)	Summer Study 1967[a]	Summer Study 1968[a]	PRC[a, b] (ref. 17) (5 case studies)
Agriculture/forestry	40-60	10's	Many 10's	1. Rice: increased production ~20 2. Wheat rust control ~300
Hydrology (water resources)	35-100	Substantial	Enormous	3. Power management ~40 (hydroelectric)
Geography (land use planning)	10-50		Many 10's	4. Malaria control ~80
Meteorology		~1000	(Not quantified)	
Geology (mined resources)	100-600	~2000	(Not quantified)	
Oceanography (marine resources)	500-900	100's	Many times greater than cost (no dollar estimate)	5. Fish: albacore tuna ~150

[a]Annual.

[b]Computed over 20-year period discounted to 1970. Annual benefits less early in period; greater late in period.

increased signal receiving and transmitting capabilities compared to systems like Intelsat which rely on large ground facilities. To make this system economically feasible a large number of small users must be identified for a single satellite. The satellite system must therefore be capable of handling a large number of signals simultaneously.

Space broadcasting.—Broadcasting from space is a possibility that should be considered. The various options include direct home radio, television to community receivers for commercial and private distribution, and television to conventional or modified home receivers.

Satellite aids to data relay.—As future unmanned satellites in Earth orbit increase their rate of data acquisition, satellite relay stations may prove to be the economical way to transmit data from any part of the orbit to ground terminals which are frequently out of line of sight. Other applications include the relay of voice, data, and possibly television from manned Earth-orbital stations to ground control centers.

NAVIGATION, TRAFFIC CONTROL, AND DATA COLLECTION

Present electronic navigation techniques are not adequate to cope with expanding air traffic and rising speeds. By 1970, the air traffic system is expected to be saturated in the North Atlantic area. A prime contributor to this situation is the fact that present poor navigation techniques, coupled with safety standards, have led to an ineffective use of airspace. Present separation requirements are 120 nautical miles laterally, 20 minutes flying time, and 2000 feet vertically. In the case of commercial or civilian ships, there is no presently available system that can provide navigational data at any time, in any kind of weather, in any part of the world.

The need here is for a satellite system that can provide rapid navigational fixes (to meet the demands of supersonic aircraft) at all times and include the small user who has inexpensive equipment that is relatively simple to operate. A single system should be capable of handling a large number of users at any one time with a minimum waiting period. It should also be capable of relaying the users' position to a control center that keeps track of all relevant

traffic in a given area and of communicating the controller's instructions to the user.

In the data-collection area, the need is for an orbital system that can locate mobile stations (e.g., balloons in the atmosphere), interrogate them for stored data, and relay this information to ground receiving stations. Fixed stations such as anchored ocean buoys and remote surface sites should also be included in the interrogation network. The capability for tens to hundreds of thousands of stations might be required.

GEODESY

Goals of the Geodetic Satellite program of the Office of Space Science and Applications (OSSA) (ref. 18) which extend beyond those cited in Space Accomplishments "as of 1968" (p. 86) include:

1. Mapping the geometry of the ocean surfaces with an accuracy of ±5 meters or better.
2. Locating certain widely separated NASA tracking stations and geophysical observation stations with an accuracy of ±1 meter or better.
3. Improving on existing measurements of Earth tides, polar motion, Chandler wobble, and the Earth's rotation rate.

Geodetic satellites may ultimately provide data on such phenomena as continental drift, vertical uplift of landmasses, and land motion along fault zones.

POST-1968 EARTH-ORBITAL SYSTEMS FOR EARTH SCIENCES AND APPLICATIONS

Having reviewed some of the future needs in the Earth Sciences and Applications program, we now wish to examine how these needs might be satisfied by an Earth-orbital program. In particular, the unmanned program projection of OSSA into the 1970's is reasonably clear in the early stages. The mid- to late 1970's projections should probably be viewed as representative of the planned level of technological effort, rather than as a specific program plan. For the manned program a preliminary payload of Earth sensors has been selected for one of the AAP workshop flights in the early 1970's. However, Earth sensing is far from a

major objective and the possibility of a second flight with Earth science/applications as one of its objectives is uncertain. It seems likely that the needs as stated will require instrumentation in Earth orbit that exceeds both the OSSA and AAP plans.

PROSPECTS FOR THE UNMANNED PROGRAM

Terrestrial Environment

As in the pre-1968 programs in this area, the emphasis is on meteorology, but data of interest to geology, oceanography, and hydrology will also be obtained. Early extensions of the basic Tiros system will incorporate the APT and AVCS camera systems (for day-side imagery) and the HRIR (for night-side imagery) on the same satellite as a prototype of a second-generation operational system. This satellite, Tiros M, should be capable of accepting additional advanced sensors in the future.

Nimbus will continue to carry developmental instruments designed to extend our knowledge of the atmosphere. Nimbus B-2 will attempt a more quantitative determination of the atmospheric structure on a global basis. The payload will include an infrared (IR) interferometer, IR spectrometer, and a solar ultraviolet (UV) experiment. In addition, an advanced television camera system will be used for the first time.

Experiments on later Nimbus flights are planned which will extend the remote sensing of the atmosphere (and the surface, except in UV) from the ultraviolet through the visible and IR on into the microwave region of the spectrum. Passive microwave radiometer and spectrometer measurements could provide key data on vertical temperature and water vapor profiles. IR sensors with improved spatial and spectral resolution would provide day and night imagery of clouds and surface features, and yield improved information on atmospheric structure. These high resolutions would require cryogenically cooled IR detectors. Microwave occultation experiments (as on Mariner IV and V) can determine atmospheric density profiles. Polarimeters in the visible spectrum might detect atmospheric pollutants.

A number of new spacecraft systems are possible here. A Synchronous Meteorology System Test Satellite has been proposed for the early 1970's to function as a precursor of an operational

system. World weather-watch satellites have been proposed for the mid-1970's for polar orbit in support of the Global Atmospheric Research Program. Finally, advanced ATS satellites in the mid- to late 1970's could provide a platform in geostationary orbit which would have a large payload capacity, long life, and be precisely oriented ($\pm 0.001^{\circ}$), for experiments such as detailed imagery of small-scale weather phenomena.

Earth Resources

For the near term, flights in the aircraft program will continue to test specific instruments and establish the so-called "ground truth" necessary for data interpretation. Specific sensors now being flown include metric and multispectral cameras, infrared imagers, microwave radiometers, side-looking radar, and radar scatterometers. There is the possibility of an Earth Resources Technology satellite in the early to mid-1970's to test some of these sensors at orbital altitudes. In the meantime, some useful data will be provided by the Tiros, Nimbus, and ATS programs.

Communications

Most of the plans here are for research on experimental systems on ATS satellites, at least through the mid-1970's. Millimeter-wave experiments are planned for ATS-E (1969). Small-user/multiple-access experiments will be extended to take advantage of large erectable antennas and precision pointing. Experiments in data relay could provide the basis for an envisioned data relay satellite system in synchronous orbit during the mid- to late 1970's.

Navigation, Traffic Control, and Data Collection

Further development of technology in this area is planned for future ATS flights. A satellite data-collection system that also locates the source data station (called Interrogation, Recording, and Location System, IRLS) was planned for Nimbus B and is currently scheduled for the Nimbus D flight. A cooperative program with the French is planned in which the positions of meteorological balloons will be determined by Doppler sounding from an orbiting satellite.

Geodesy

Follow-on flights in the Geodetic Earth-Orbiting Satellite Program, carrying accurate laser or radar altimeters, might be used for measurements of the shape of the ocean surface. Such measurements might also be done from advanced ATS satellites in the mid-1970's.

PROSPECTS FOR THE MANNED PROGRAM

Aside from Apollo test flights, the only scheduled program of manned Earth-orbital missions is AAP. A number of Earth resources/meteorology experiments have been reviewed by NASA as part of the payload on one of these flights. These experiments include cameras, IR spectrometers and interferometers, and a microwave radiometer. As currently planned, only one experiment–a multispectral camera–has much chance of being flown. This would be on a workshop flight with an orbital inclination possibly as high as 35°. There will probably also be more Apollo photography with handheld cameras.

Most of the Earth-sensing experiments proposed for the AAP time period are similar to experiments proposed for the unmanned satellite program. However, in the post-1975 era there may be the need for very large and complex systems in Earth orbit which go beyond those discussed in the earlier part of this section. For example, in the communications area, direct television transmission to homes at UHF frequencies should be done with a system in synchronous orbit and requiring a kilowatt of power and a 100-meter diameter parabolic antenna. While a smaller satellite system could be used in conjunction with community receiving and distribution stations, this may not be cost effective in areas of sparse population where the number of television sets per distribution station is small.

For navigation and traffic control systems, a large space-radio interferometer using phase comparison between microwave signals received at two antennas located tens of meters or more apart on an accurately known baseline might prove desirable. Pulsed laser radars (ref. 19) operating at suitable wavelengths have the potential for measuring a wide cross section of atmospheric parameters, including the distribution of key constituents–O_2, H_2O, CO_2–as well as particulate matter. This fact is especially important for the heat-budget problem.

The merits of putting any of these instruments on a manned station are discussed in the following section.

MAN'S INTERACTION WITH THE INSTRUMENTS IN EARTH ORBIT

Man in an Earth-orbital station could have two fundamental types of interaction with the Earth sciences and applications instrumentation. In the first case discussed below, he acts as a technician and observer to check out, maintain, and operate instruments that were developed and tested on the ground. In the second case, also discussed below, he functions as a development engineer on the space station. His intent here is to carry out the design and performance evaluation, at various stages in the development of a new instrument, by testing it at the task for which it is designed. Once this development phase ends, the new instrument proceeds to manufacturing. Subsequent to this, the man in the space station again becomes technician and observer during the operation phase of the instrument.

INSTRUMENT CHECKOUT, MAINTENANCE, AND OPERATION

Basically, the Earth sciences and applications payload consists of instrumentation through which information flows. Even if he has very little or no personal contact with this information, man might still act as a useful technician. If he has contact with the information, he can be an observer and, no doubt, a better technician.

As a technician only, possible functions include assembling and positioning of instruments. One class of assembly might involve large structures such as antennas requiring EVA. Smaller instruments might be moved from launch storage areas and placed in proper position for operation. Calibration and alinement of equipment are functions that could be carried out at regular intervals during a mission. This could be done by having a calibration source on the spacecraft or elsewhere, as long as the source properties were known. Alinement, such as focusing a camera, could be done entirely on the spacecraft or with supporting

instructions from the ground, after an observer there had reviewed some information on equipment operation. Carrying out these functions in space would relax the requirement that such adjustments survive launch.

Once the equipment is set into operation (i.e., following assembly, alinement, and calibration), there will ultimately be a need for maintenance and repair. If he is not in personal contact with the information flow, the man onboard will have to be instructed from a ground base as to what the symptoms of the malfunction were. Exactly what types of repair operations could be performed would depend on factors such as basic equipment design and the ability of man to manipulate objects in the spacecraft environment.

For the man onboard to intercept the information flow, proper data displays are required. This applies equally to an infrared imagery experiment or to a broadcast system (although in the latter case the sensor that actually measures equipment performance is likely to be on the ground).

If, in addition to displays, the man onboard has both the time and ability to react, he can perform some function as a scientific observer, responding to objects of opportunity. The apparent rate of motion of the Earth's surface from a 200-mile orbit is comparable to that from a 600-mph jet plane at 35 000 feet; so that even in the lower orbits there is a reasonable reaction time. The ability to react is a function of the man-machine interface. For example, if the man should be observing a real-time display of radar scatterometer data, and he noticed something unusual, he must have the ability to train another sensor on the same area to take additional data.

Another function of the observer is to alter the mode of operation of a given instrument, either because incorrect operating conditions were initially assumed, or because it was found during the flight that productive data could be acquired in several different modes. These alterations might include changing filters and resetting gain levels, exposure times, scan rates, or transmitted power level.

EXPLORATORY INSTRUMENT DEVELOPMENT

As experience is gained in the use of sensors and other instruments in Earth orbit, we can obtain a better understanding of what the most desirable instrument parameters would be, at least conceptually. Some of these ideas will be developed into new, second- or third-generation instruments. If man is reasonably adept in the maintenance, repair, and operation of instruments on an orbital station, he may also have a role in the development and engineering shakedown phases of new instrumentation for orbital use. For example, in the early development stages when many design choices are available, a working breadboard could be installed on the station. The cognizant engineer could accompany it, perform manual functions, analyze and discuss the data with his cohorts on the ground, and make modifications in situ.

In the advanced phases of development, there may be very real advantages in performing qualification tests and engineering shakedown in space. Thermal vacuum chambers and solar simulators are expensive and imperfect. Direct tests in space are less controlled (e.g., because of Earth occultation), but more realistic.

Shakedown involves operation of the final device. On Earth it is customary to have a continuing capability for tuning and last-minute changes. If difficulties arise that the man in the space station cannot handle, the device can be returned to Earth for further work.

CRITICAL ISSUES

The concept of a large space station capable of placing man in contact with a substantial payload, possibly involving a mix of instruments from each of the five categories selected for discussion (Terrestrial Environment; Earth Resources; Communications; Navigation, Traffic Control, and Data Collection; and Geodesy), raises two critical issues.

One issue is the question of interference. This could be instrument/instrument interference, where the requirements for operation of one instrument are mutually incompatible with the requirements for operation of another. This could mean that such instruments would have to be flown separately, detracting from some of the advantages of the space station "bus" concept. There is also a class of man/instrument interference in which either man himself or the subsystems necessary to support him create an

environment that is incompatible with the requirements for operation of certain instruments. Examples of these are given below.

INSTRUMENT/INSTRUMENT INTERFERENCE

Electromagnetic Interference

Two categories in the Earth applications area–(1) communications and (2) navigation, traffic control, and data collection–will involve electronic systems on the spacecraft which use extremely large amounts of power, some of which will be radiated throughout the spacecraft environment as electromagnetic noise. These systems will probably be operating full time if they are to perform a useful service. Many of the sensors will be sensitive to such a high electrical-noise background. They must either be shielded, if possible, or carried on another spacecraft.

Radiation Interference

For instruments that require large amounts of power, nuclear power supply may be the most efficient source. Heat and nuclear radiation may interfere with remote-sensor detection equipment.

Mechanical Coupling

Some instruments require a very stable mechanical configuration; these include interferometers and camera optics. Any excessive motion on the spacecraft will interfere with their performance. Other instruments require mechanical motion that could be a source of interference; these include scanning radiometers and cameras. In addition, mechanical motion that changes the attitude of the spacecraft would interfere with navigation systems that depended on precisely maintained spacecraft attitude.

Orbital Parameters

Different instruments require different orbits. Geodesy is probably an extreme example in which the orbital parameters are essentially tuned to the characteristics of the gravitational field one wishes to measure. In general, these orbits will be elliptic, with low-periapsis altitude and a variety of inclinations. In most other

categories of measurements and operations, medium altitude, circular polar orbits, or synchronous orbits are preferred.

MAN/INSTRUMENT INTERFERENCE

Orbital Position Perturbation

Man plus his life-support system produce an active spacecraft with certain uncontrollable motions. This essentially rules out man's presence on a gravimetric geodesy satellite, as it would be virtually impossible to separate the spacecraft motion caused by onboard effects from that caused by gravitational effects. While geodesy is probably the most sensitive case, orbital position is also quite important for navigational purposes.

Mechanical Coupling

Onboard motion of man and mechanical disturbances caused by his support systems (leaking cryogenic supplies, rotating machinery) will interfere with instruments requiring a precise mechanical configuration, as pointed out above. These disturbances and subsequent motions may also be incompatible with systems requiring stable and accurate attitude control, such as for navigation.

Orbit Selection

Placing man in the spacecraft may constrain the possible orbits, for example, to avoid the radiation belts. Daily coverage of all points on Earth can be achieved from polar orbit at altitudes of 1000 to 1500 kilometers where the radiation hazard is quite severe. This hazard is reduced to levels that are tolerable with present shielding arrangements at altitudes of 300 to 500 kilometers, but here the coverage is less frequent, averaging only once every several days. The degree of hazard at synchronous altitudes is comparable to that at 500 kilometers.

ECONOMICS

The second critical issue is basically one of economics. The interference constraints can be offset by dividing all the instruments one wishes to fly into a set of individually compatible payloads.

Some of these could have a man onboard to perform the functions outlined in the previous section, and others could not. Man could have essentially four classes of interaction with the payload. The first two require manned space flight and include permanent occupancy of the station or occasional visits at times when maintenance, repair, etc. are required. The visit type of interaction would be the only possibility for those payloads where man's presence during operational periods would cause interference. The second two classes do not require manned flight. One option would be to return the payload to Earth for manned repair and relaunch. The other option would be to have no manned interaction with the payload at all; this would mean either terminating the particular function of the malfunctioning payload or replacing the payload altogether.

Economic tradeoffs are certainly an important factor in determining which of the four options to pursue. The 1967 President's Science Advisory Committee report (ref. 20) made the following comment on scientific observation of the Earth from Earth orbit: "... we recommend that in the comparison of manned versus unmanned modes of carrying out research in this field the criterion of relative total cost effectiveness be applied to the extent possible." Their recommendation on Earth applications was somewhat more definitive, probably reflecting the difficulty of attaching a price tag to science—"we recommend: That, whether the proposed space applications systems are manned or unmanned, a reasonably clear case of potential utility must be made, which includes an assessment of potential economic benefit, before significant development costs are assumed."

Evaluating the economic benefits of having a working facility in orbit is probably the easier problem. Attaching economic significance to the role of man is more difficult. What makes this difficult is not having a real understanding of the man/machine interface in the spacecraft environment. When we use words like calibrate, maintain, and repair in the context of an Earth laboratory, this might imply either a rather rudimentary or a very sophisticated result. At this stage in our space-flight experience, it is extremely difficult to describe quantitatively what man's contribution to the success of the Earth sciences/applications mission would be.

RECOMMENDATIONS

The needs in the Earth Sciences and Applications program call for a vigorous program of Earth-oriented space activities in the 1975 to 1985 time period. It is likely that the best strategy for pursuing these needs will involve a mix of both manned and unmanned space activities. Of the various criteria that should be used to determine this mix, economics is certainly a key factor. Further experiments and study to determine just what contribution man would make to the operation of an instrumented station in Earth orbit are required before the larger question of the manned/unmanned mix can be successfully considered.

REFERENCES

1. Objectives and Goals in Space Science and Applications 1968. NASA SP-162, 1968.
2. Exploring Space with a Camera. NASA SP-168.
3. Lowman, P. D.: Geologic Applications of Orbital Photography. NASA TN D-1455, 1967.
4. Space Science and Applications Program. NHB 8030.2B, 1968.
5. Thomas, P. G.: Global Weather Forecasting. Space/Aeronautics, Oct. 1967, pp. 76-89.
6. Space Applications Summer Study, 1967 Interim Report. Vol. II. NAS (draft).
7. Houghton, H. G.: On the Annual Heat Balance of the Northern Hemisphere, Meteorol. vol. 2, 1954, pp. 1-9.
8. Manabe, S.; and Wetherald, R. T.: Thermal Equilibrium of the Atmosphere with a Given Distribution of Humidity. J. Atm. Sci., vol. 24, 1967, pp. 241-259.
9. Moller, F.: On the Influence of Changes in the CO_2 Concentration in Air on the Radiation Balance of the Earth's Surface and on Climate. J. Geophys. Res., vol. 68, pp. 3877-3886.
10. Plass, G. N.: Carbon Dioxide and the Climate. Am. Scientist, vol. 44, 1965, pp. 302-316.
11. Peterson, J. T.; and Bryson, R. A.: Atmospheric Aerosols: Increased Concentrations during the Last Decade. Science, vol. 162, 1968, pp. 120-121.
12. Weather and Climate Modification–Problems and Prospects. Vol. I, no. 1350. NAS-NRC, Wash., D. C., 1966.
13. Earthquake Prediction–A Proposal for a IV-Year Program of Research. Office of Science and Technology, 1965.
14. Oceanography 1966–Achievements and Opportunities. Pub. 1492. NAS-NRC, 1967.
15. "An Icy World Yields Its Secrets." The Washington Post, Nov. 24, 1968.
16. Waltz, Donald: Technological Base for Planning of Spaceflight Missions to Obtain Data on the Earth's Resources. TRW Systems, incl. AIAA paper no. 68-1074, 1968.
17. Muir, A. H.; and Summers, R. A. (NASA): The Use of Economic Benefit Analysis in Earth Resources Satellite System Planning. Planning Res. Corp., AIAA paper no. 68-1077, 1968.
18. Space Applications Program Memorandum. NASA Space Appl. Working Group, July 15, 1968.
19. Analysis of a Satellite-Borne Meteorological Laser Probe. Electro-Optical Systems, Inc., Proposal D012A-51, 1966.
20. The Space Program in the Post-Apollo Period. PSAC Report, Feb. 1967.